Student Textbook page 95

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1. 2.55×10^3 g

2. 1.1 m^2

3. 1.7 kN

4. 1.42×10^7 cm^3

5. 380 g

6. 39.95 g/mol

Student Textbook page 101

1. Gases expand when heated. This is important for ballooning because as the air inside the balloon expands, it reduces the density of air inside the balloon to less than the density of air outside the balloon and creates a net buoyant force on the balloon.

2. Gases are highly compressible. This is important for scuba divers because several hours' worth of air can be put into a scuba tank small enough for the diver to carry.

3. (a) Gases are compressible. Since gases are compressible, they cannot be sold by volume, but are instead sold by mass. Most tanks used on domestic barbeques will hold 9 kg of propane.

(b) Gases expand as the temperature is increased if the pressure remains constant. When a can of hairspray is heated, the volume of the gas will be become too large to be contained by the can and the can will explode.

(c) Gases have a very low resistance to flow and mix evenly and completely. Many toxic gases are also colourless and odorless, which makes them even more dangerous to transport.

(d) Gases mix evenly and completely and have a low resistance to flow, which makes it much easier to move the hot gas through a building. Large buildings cannot be heated with forced air, however, because air's low specific heat capacity compared to water does not permit the storage of sufficient energy to heat a large area.

(e) Gases have low viscosity. When a hole in a bicycle tire appears, it takes very little time for the air to squeeze out through the hole. (One way to measure viscosity is to see how quickly a fluid (i.e., a liquid or gas) can get through a small opening.)

4. The space between gas particles is huge compared to the size of the particles themselves. We can simplify the kinetic molecular theory by assuming that the particles have negligable size but do still have a mass.

5. No kinetic energy is lost by the particles in an elastic collision. In an inelastic collision, some or all of the kinetic energy is lost by the particles in the form of heat.

6. The definition of an ideal gas assumes that the total kinetic energy of a gas sample is conserved when the particles collide with one another and with the container. In other words, the collisions are elastic. Collisions in real gases are inelastic, therefore some kinetic energy is converted to thermal energy and may be transferred from the system to the surroundings.

7. Real gases behave differently from ideal gases when they get close to their condensation points. At these temperatures, the particles are close enough together and moving slowly enough that interactions between them cannot be ignored.

8. Figure (a), since it shows a random pattern to its motion, with straight lines of travel between collision with the container wall and other particles.

9. (a) The molecules of a second gas are able to fit into the spaces between the molecules of the first gas.

(b) The molecules are in constant random motion, so if the container is expanded the molecules will travel further before contacting the walls of the container.

(c) Because there are relatively large spaces between molecules in gases and no repulsive forces, the molecules in gases can be easily pushed closer together.

Student Textbook page 104

Q1. As the altitude increases there is less air on top of the air at that altitude. As a result the particles aren't forced as closely together thus lowering the density.

Q2. Depends on the type of barometer, but a mercury barometer works by allowing air pressure to hold up a column of mercury. As the air pressure rises, the air can support a higher column of mercury.

Q3. To convert pressure in mmHg to pressure in kPa, multiply the pressure in mmHg by $\frac{101.325\ \text{kPa}}{760\ \text{mmHg}}$.

Q4. Standard atmospheric pressure is defined as the atmospheric pressure in dry air at 0 °C at sea level and is 101.235 kPa or 760 mmHg.

Student Textbook page 110

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1. 24 L

2. 2.00 atm or 203 kPa

3. 2.25 L

4. 2.0 L

5. 1.03 bar

6. 0.97 atm

Student Textbook page 112

1. A mercury barometer (and all barometers) are based on the premise that the pressure that the atmosphere exerts on a dish of mercury will be equal to the height that the mercury is pushed up inside a sealed column overturned in the dish. The column is first filled with mercury completely and then turned over in a dish containing more mercury. A vacuum is created inside the column when the mercury flows out due to gravity. The more the mercury flows out (the shorter the column of mercury), the lower the atmospheric pressure pushing it back. Original water pumps functioned on this same principle. A pump created suction at the top of a column of water similar to the vacuum created in the mercury column. The atmospheric pressure pushing on the water coupled with the vacuum created by the pump caused water to rise in the column. Atmospheric pressure can push water up a column to a maximum height of approximately 10 m.

2. (a) $3.58 \cancel{\text{bar}} \times \dfrac{101.325 \text{ kPa}}{1.01325 \cancel{\text{bar}}} = 358 \text{ kPa}$

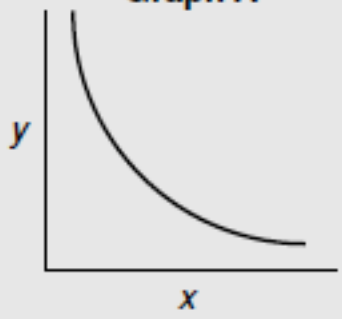
(b) $850 \cancel{\text{mmHg}} \times \dfrac{101.325 \text{ kPa}}{760 \cancel{\text{mmHg}}} = 113 \text{ kPa}$

(c) $1.75 \cancel{\text{atm}} \times \dfrac{101.325 \text{ kPa}}{1 \cancel{\text{atm}}} = 177 \text{ kPa}$

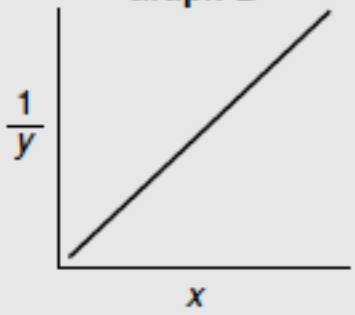
3. (a) 1.25 atm **(b)** 1.5 bar **(c)** 105 kPa **(d)** 1.25 atm

4. An inverse relationship is suspected when as one variable increases, the other decreases. The shape of an inverse relationship is a curve, as shown below in graph A. To test this hypothesis, a graph of x vs 1/y should be drawn. If, when drawn, a straight line is observed, then the variables are inversely proportional, as shown in graph B.

Graph A



Graph B



5. Since the pressure has tripled, the volume will drop to one third of its value, becoming 0.83 L.
6. From 10 mL to 5 mL, the volume is halved. This requires double the pressure. Going from 10 mL to 15 mL increases the volume by 1.5 times and requires that Raja lower the pressure to two-thirds of its old value. The first push created a bigger pressure difference.
7. $V = 5.0\ \text{L} \times \frac{95.8\ \cancel{\text{kPa}}}{20.6\ \cancel{\text{kPa}}} = 23\ \text{L}$
8. $3.35\ \cancel{\text{atm}} \times \frac{101.325\ \text{kPa}}{1\ \cancel{\text{atm}}} = 339.4\ \text{kPa}$

   $V = 2.5\ \text{L} \times \frac{100\ \cancel{\text{kPa}}}{339.4\ \cancel{\text{kPa}}} = 0.737\ \text{L}$
9. Boyle's law states that as the volume of a fixed mass of gas decreases, the pressure increases proportionately. One application of Boyle's law is in the functioning of our respiratory system. When our diaphragm drops, it decreases the pressure inside our lungs, which causes an increase in volume, drawing air into our lungs.

10. $V = 10\ \text{L} \times \dfrac{1.75 \times 10^4\ \cancel{\text{kPa}}}{101.325\ \cancel{\text{kPa}}} = 1.73 \times 10^3\ \text{L}$

11. As the pressure around the gas sample drops, the gas will push outward and expand until the internal and external pressures are equal.

12. Sara should determine whether the atmospheric pressure has changed. The balloon could be smaller either because of an increase in atmospheric pressure, or because some of the gas has escaped from the balloon.

13. The student must assume the temperature is the same on both days, and that none of the oxygen gas has escaped.

$$P = 102.1\ \text{kPa} \times \frac{27.3\ \cancel{\text{mL}}}{27.9\ \cancel{\text{mL}}} = 99.9\ \text{kPa}$$

14. Water is not "drawn up" into a straw. Atmospheric pressure on the surface of the liquid pushes water up a straw in which a partial vacuum has been created. When the atmospheric pressure becomes higher, it takes a smaller partial vacuum to cause water to rise in the straw.

Student Textbook page 116

Q5. The Kelvin scale is based on two things: Firstly it starts from absolute zero and secondly, it uses degrees the same size as Celsius degrees.

Q6. A volume of zero is impossible if atoms take up any space (they do). Atoms of an ideal gas have zero volume.

Q7. Absolute zero is a theoretical value determined by extrapolating a volume versus temperature graph.

Q8. 310 K

Q9. –196 °C

Student Textbook page 118

Q10. $V = mt + b_n$

$V - b_n = mt$

$$t = \frac{V - b_n}{m}$$

Q11. Charles's Law, $V_1/T_1 = V_2/T_2$ is based on the relationship between volume and temperature where the graph passes through the origin. If the temperature is measured using the Celsius temperature scale, the value for the y-intercept, which will change with changing pressure, must be included in the calculations.

Student Textbook page 119

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7. (a) 300.4 K

(b) 311.0 K

(c) 395.6 K

(d) 248 K

(e) 233 K

8. (a) 100.0 °C

(b) 2 °C

(c) –100 °C

(d) –249.6 °C

(e) 600 °C

9. 0.29 L or 2.9×10^2 mL or

10. No, 3.2 L

Student Textbook page 120

11. 308 K

12. Kelvin temperature is 1.25 times room temperature.

13. 606 °C

14. –214 °C

Student Textbook page 121

Q12. A direct proportion exists between two variables if, when one variable increases, the other increases at the same rate. This relationship exists between the volume and temperature (in Kelvins) of a fixed mass of gas. If the Kelvin temperature of a gas is doubled, then the volume will also double (if pressure is constant). An inverse proportion exists between two variables if, when one variable increases, the other decreases at the same rate. This relationship exists between the pressure and volume of a fixed mass of gas. If the pressure of a gas is doubled, then the volume will halve (if temperature is constant).

Q13. Charles's Law is based on a direct proportion between volume and temperature. This relationship only exists with temperatures measured in Kelvins, so temperature must be measured in Kelvins. The reason this relationship exists is because at 0 Kelvins (absolute zero), the volume of any gas will also be zero. The Kelvin temperature scale is based on this fact, while the Celsius scale is based on water. If the Celsius scale is used, then there will be another term in the Charles's law calculations, making the math much more difficult.

Student Textbook page 122

1. The balloon floats because helium is less dense than the air around it. Above the barbecue the hot air expands, becomes less dense than its surroundings, and rises. This carries enough thermal energy to the balloon that it expands the gas inside, causing the balloon to break.

2. The air inside the tire should be at a high enough pressure that the force inside the walls of the tire is high enough not only to keep the tire hard but to support a quarter of the car's weight. If tires are thumping, the inside pressure isn't high enough, so the tire needs more air.
3. The aerosol can is a closed container with a constant volume. When a gas at constant volume is heated its pressure rises. The danger here is that the pressure inside the can may increase to exert a force stronger than the strength of the can, causing it to explode.
4. The graph shows that the volume of a gas increases as its temperature increases. The *y*-intercept of the graph should be 92 mL. The *x*-intercept of the graph should be –273 °C, demonstrating that in theory, at absolute zero, the volume of an ideal gas is zero. For temperature in Celsius, the equation of this graph, determined by the relationship $y = mx + b$, is $y = 0.34x + 92$.
5. $V = 6.0\ \text{L} \times \frac{450\ \text{kPa}}{200\ \text{kPa}} = 14\ \text{L}$
6. $V = 3.9 \times 10^2\ \text{L}$
7. $V_1 = 2.0\ \text{kL}$

$V_2 = ?$

$T_1 = 6.00\ °\text{C} = 279.15\ \text{K}$

$T_2 = 25\ °\text{C} = 298\ \text{K}$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$V_2 = \frac{V_1 T_2}{T_1}$$

$$= \frac{(2.0\ \text{kL})(298\ \text{K})}{(279.15\ \text{K})}$$

$$= 2.1\ \text{kL}$$

8. $V_1 = 2.5\ L$

$V_2 = 2.0\ L$

$T_1 = 24.2\ °C = 297.4\ K$

$T_2 = ?$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$T_2 = \frac{V_2 T_1}{V_1}$$

$$= \frac{(2.0\ L)(297.4\ K)}{(2.5\ L)}$$

$$= 237.9\ K$$

$$T\ (\text{in } °C) = 237.9\ K - 273.15\ K$$

$$= -35\ °C$$

9. $T_1 = 25\ °C + 273.15 = 298\ K$; $T_2 = -20\ °C + 273.15 = 253\ K$

step 1: $V = 600\ L \times \frac{253\ K}{298\ K} = 509\ L$

step 2: $V = 509\ L \times \frac{P_1}{4P_1} = 1.3 \times 10^2\ L$

10. As the air inside the balloon heats up, either the pressure inside the balloon must increase, or the air must expand. The pressure inside the balloon remains constant to balance the atmospheric pressure on the outside, so the air must expand. The balloon envelope is fairly rigid when inflated, but the air can escape at the bottom of the balloon. This reduces the density of air inside the balloon making it more buoyant, so that it rises.

11. **(b)** is invalid as there is no direct or indirect relationship between the Celsius temperature and pressure. If, as in **(a)**, the Kelvin temperature of a gas is doubled and the volume is held constant, the pressure will double.

Student Textbook pages 124–125

1. Boyle's law is illustrated by **(a)**.
2. Charles's law is illustrated by **(e)**.
3. Example b. can be explained by a combination of the two laws.
4. **(a)** The column of mercury would get gradually shorter as it moved up the mountain. The air pressure outside is getting lower, as the column moves from sea level to a mountain.
5. A straw will not work for drinking water if it is longer than 10.3 m, even when attached to a vacuum pump. In practice, for lengths far less than this, the sides would crush together instead of pulling water up any great distance.
6. Absolute zero is the temperature at which the volume of a gas becomes zero. This cannot really happen in practice but until the temperature gets near absolute zero it is a good approximation. It was originally thought that molecular motion would cease at absolute zero, but today absolute zero is defined as the temperature at which molecular motion is at a minimum.
7. The particles of a gas are much farther apart in the particles of a liquid or gas. Therefore there is less mass in a given volume and hence a lower density.

Answers to Applying Concepts Questions

8. **(a)** False: the freezing point of water is 0 °C.
   (b) Likely true, since 313 K = 40 °C.
   (c) False; for example, –40 °C is still 233 K.
   (d) False: 310 K = 37 °C, which is normal human body temperature.

9. See answers to question 8.
10. Graph B correctly represents the relationship between the pressure and volume of a fixed mass of gas. Volume is inversely proportional to pressure, so as pressure increases, volume decreases, as shown in graph B. Graph C is incorrect as it does not display an inverse proportion. Only when volume and 1/pressure are graphed should there be a straight line.

Answers to Problem Solving Questions

11. $P = 101\ \text{kPa} \times 50\ \text{mL} / 14\ \text{mL} = 361\ \text{kPa}$
$= (3.6 \times 10^2\ \text{kPa})$
12. $V = 27\ \text{L} \times 308\ \text{K} / 293\ \text{K} = 28.4\ \text{L} = (28\ \text{L})$
13. $V = 89\ \text{kPa} \times 1.5\ \text{L} / 101.3\ \text{kPa} = 1.3\ \text{L}$
14. $T = 295\ \text{K} \times 2.8\ \text{mL} / 10\ \text{mL} = 83\ \text{K}$
15. The pressure must be multiplied by 5 times to about 38 atm.
16. Let the gas in the tank expand to the pressure in the balloons:
$V = 15\ 000\ \text{kPa} \times 5\ \text{L} / 115\ \text{kPa} = 652\ \text{L}$

Divide by the volume of one balloon to get:
652 L / 2 L per balloon = 326 balloons ($= 3.3 \times 10^2$ balloons)

17. $P = 110\ \text{kPa} \times 19\ \text{L} / 1.0\ \text{L} = 2090\ \text{kPa} = (2.1\ \text{MPa})$
18. $P = 1273\ \text{K} \times 5.00\ \text{atm} / 295\ \text{K} = 22\ \text{atm}$
19. $P = 102.3\ \text{kPa} / 101.3\ \text{kPa} = 1.010\ \text{atm}$
Height of Hg is $1.010\ \text{atm} \times 760\ \text{mmHg} = 768\ \text{mmHg}$

20. When the volume of air on the right side of the tube is compressed to one third its volume, the mercury on the right will move down (and up the right side) 10 mm. This mercury must be replaced. To compress the volume of the air to one third its original volume, the pressure must be increased three fold. The atomsphere provided one atm of pressure so mercury must provide two more atmospheres of pressure or 2×760 mmHg. Therefore, $2 \times 763 + 10 = 1530$ mmHg.

Answers to Making Connections Questions

21. (a) As altitude increases, atmospheric pressure decreases. The temperature required to have the vapour pressure equal the atmospheric pressure is lower at higher altitudes as a result.

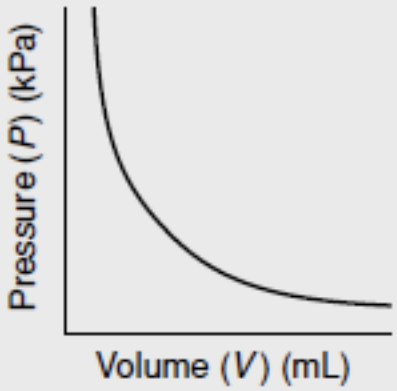
(b) Using the data provided, the predicted boiling point would be 90.0 °C.

22. At the higher altitude, the atmospheric density is lower than at sea level. To carry enough oxygen from the lungs to body tissue, more red blood cells are necessary.

23. To efficiently transport gases, they are often transported under pressure. This allows for larger quantities of gas to be shipped, although they must then be shipped under higher pressures, which adds to the safety concerns. To address these safety concerns, a container must ensure that the gas remains contained and any leak would be quickly identified. Since gases expand when heated (which leads to an increase in pressure, which in turn would make a leak more likely and dangerous) containers should be insulated from the heat and made from materials that reflect heat well. The temperature of the gas inside the container should be carefully monitored and temperature should be controlled using refrigeration. Any leak would

be identified by a decrease in pressure, so containers should be equipped with very sensitive pressure gauges that would measure any changes in pressure.

24. Experimental Design: Fill the syringe with 10.0 mL of air. Connect the syringe to the tubing and the pressure gauge. Record the initial volume of the air in the syringe (assume the volume of air included in the tubing is negligible). Record the pressure on the pressure gauge. Press on the plunger of the syringe until the volume reads 8.0 mL. Record the pressure on the pressure gauge. Vary the volume of air in the syringe, recording both the volume of air and the corresponding pressure on the pressure gauge for values from 25.0 mL to 5.0 mL. The relationship obtained should be similar to the graph below:



25. Since the volume of air will vary with temperature, you could build a thermometer using a reservoir of air contained in an Erlenmeyer flask. Thread the glass tubing into a one-holed rubber stopper. Use a pipette bulb to draw up a small amount of coloured water into the glass tubing. Put your finger over the top of the tubing to ensure the water remains trapped. Seal an Erlenmeyer flask with the rubber stopper. The mass of air in the

Erlenmeyer/glass tubing is now fixed. Calibrate your thermometer by heating the Erlenmeyer in a water bath and recording the level of the coloured water in the tubing at specific temperatures measured with a thermometer. Since the volume of a gas is not only affected by temperature but also by pressure, an open-ended thermometer such as this one will also be affected by variations in atmospheric pressure.